FISHERY RESEARCH

LAKE PEND OREILLE PREDATION RESEARCH

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Prepared by:

Thomas P. Bassista
Senior Fisheries Research Biologist

Melo A. Maiolie
Principal Fisheries Research Biologist

and

Mark A. Duclos
Fisheries Technician

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Lake Pend Oreille Predation Research

Project Progress Report

2003 Annual Report

By

Thomas P. Bassista
Melo A. Maiolie
Mark A. Duclos

Idaho Department of Fish and Game
600 South Walnut Street
P.O. Box 25
Boise, ID 83707

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U.S. Department of Energy
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ABSTRACT

During 2003, we investigated the feasibility of performing mobile hydroacoustic surveys in the limnetic zone of Lake Pend Oreille, Idaho during spring (May) and summer (August) to estimate rainbow trout *Oncorhynchus mykiss* abundance. If we had the ability to enumerate pelagic predator and prey populations annually, we may be able to determine what ratio constitutes a balanced system. By bringing pelagic predator and prey populations to balance, we would be better equipped to recover the kokanee *O. nerka* fishery, which was closed to harvest in 2000 due to high predation rates. In order to develop a successful hydroacoustic survey, we needed to identify fish groups located on echograms. Therefore, we utilized a combination of sonic telemetry, pelagic gillnetting, and midwater trawling to help identify unknown targets. Our results indicated that spring and daytime (spring and summer) surveys were ineffective times to enumerate pelagic predators, and that nighttime surveys performed in August may provide the best thermal conditions to estimate pelagic predators. Additionally, habitat use of nine lake trout *Salvelinus namaycush* and five bull trout *S. confluentus* during the summer suggested that these two species were predominantly found in benthic and nearshore areas and, therefore, not fully accounted in our hydroacoustic analysis of the pelagic area. We estimated that the population of large pelagic fish was 11,733 (7,007 to 17,251 ± 90% CI) with a total weight of 30.5 tonnes, assuming all fish had the length-weight relationship of rainbow trout. This produced a 1:8.6 (kg) ratio of potential pelagic predator to kokanee prey. A concerted effort will be made in 2004 to investigate the habitat use of rainbow trout to determine what portion of the pelagic fish population estimate may be comprised of rainbow trout, a significant pelagic predator of kokanee in Lake Pend Oreille.

Authors:

Thomas P. Bassista
Senior Fisheries Research Biologist

Melo A. Maiolie
Principal Fisheries Research Biologist

Mark A Duclos
Fishery Technician

INTRODUCTION

Recent studies suggest that kokanee *Oncorhynchus nerka* recovery in Lake Pend Oreille was being impaired by predation; consequently, harvest regulations were implemented to reduce kokanee mortality. Vidergar (2000) concluded that predators, namely rainbow trout *O. mykiss*, bull trout *Salvelinus confluentus*, and lake trout *S. namaycush* collectively constitute a major source of predation on kokanee with rainbow trout having the greatest impact of predation. His work was based on mark-and-recapture population estimates and bioenergetic modeling of predators. Maiolie et al. (2002) examined kokanee survival rates, production, biomass, and yield to determine if predators were having an impact on the kokanee population. They concluded that predation levels were too high for the kokanee prey base. To reduce predators, specific fishery rule changes were put into action in February 2000. The kokanee fishery was closed to all harvest. Harvest and size limits were changed for rainbow trout (from two fish >510 mm total length [TL] to six fish of any size), and fishing season for rainbow trout from a boat was opened to year-round instead of the last Saturday in April to the end of November. The bag limit for lake trout was eliminated. In addition, the Clark Fork River below the Railroad Bridge at Clark Fork, Idaho was open all year to fishing with the same limits as the lake for a 4-year period starting in February 2000. After January 2004, the Clark Fork River below the Railroad Bridge was only open for the general (May 29-November 30) and winter (catch-and-release December 01-March 31) stream fishing seasons.

Maiolie et al. (2002) recommended developing a hydroacoustic method to estimate rainbow trout abundance. By having the ability to monitor kokanee and pelagic predator abundance annually, we may be able to implement management actions designed to help balance predator and prey populations and improve kokanee age-1 and age-2 survival rates. A proper balance between predator and prey populations is one component necessary to help recover the kokanee population and fishery in Lake Pend Oreille, and it may help compliment improvements in spawning habitat that were shown to increase egg-to-fry survival (Maiolie et al. 2002).

Until the proper tools to enumerate the predator population can be developed, kokanee survival may be used as a surrogate for determining predation levels. Maiolie et al. (2002) suggested that the survival rate of kokanee between age-1 and age-2 could be used as a sensitive indicator of kokanee predation. Vidergar (2000) most often found these age classes in rainbow trout stomachs. From 1996 to 2002, average kokanee survival from age-1 to age-2 was approximately 40%, well below the average of 80% between 1985 and 1996. Kokanee survival from age-1 to age-2 did increase from a low of 18% in 1999 to 55% in 2003, indicating that predator and prey levels may be nearing a balance. However, caution should be used while examining 2003 kokanee survival rates, because low numbers of kokanee in future age classes were predicted (Maiolie et al. 2004).

The purpose of our research (March 2003—February 2004) was to investigate the spring and summer use of downlooking mobile hydroacoustics for determining population estimates of large pelagic fish >-33 dB (415 mm) (Love 1971) in Lake Pend Oreille (fall and winter periods were examined in Bassista and Maiolie 2004). A cutoff size of –33 dB was used because it was a size large enough to distinguish kokanee from large pelagic fish found on hydroacoustic echograms. Our major tasks included determining the depth distribution of hydroacoustic targets >-33 dB and attempting to identify those unknown targets using a combination of sonic telemetry, pelagic gillnetting, and midwater trawling. Our summer telemetry efforts in 2003 were only focused on bull trout and lake trout because no tagged rainbow trout survived into summer.

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Additionally, we established a large pelagic fish biomass estimate (summer only), then we determined a potential pelagic predator and prey (kokanee) biomass ratio and discussed its implications for predator management. Finally, we discussed potential methods for removing rainbow trout and examined the depth use and movements of bull trout and lake trout in relation to trap netting efforts (see Peterson and Maiolie 2004 for trap net results). This work was the second year (March 2002-February 2005) of progress in a multi-year investigation of hydroacoustic techniques to enumerate rainbow trout and balance the predator and prey communities.

STUDY AREA

Lake Pend Oreille is located in the northern panhandle of Idaho. It is Idaho's largest lake and has a surface area of 38,300 ha, a mean depth of 164 m, and a maximum depth of 351 m. It is a natural lake, but two hydroelectric facilities influence the lake level and restrict upstream fish passage. Cabinet Gorge Dam, located upstream on the Clark Fork River, modifies water flow into the lake and blocks historical upstream spawning and rearing areas for salmonids. Albeni Falls Dam, located downstream on the Pend Oreille River, regulates the top 3.5 m of the lake (Figure 1). Summer pool elevation (July-September) is about 628.7 m, and winter pool level is typically between 625.1 to 626.4 m.

Lake Pend Oreille is a temperate, oligotrophic lake. The average summer water temperature (May to October) is approximately 9°C in the upper 45 m of water (Rieman 1977; Bowles et al. 1987, 1988, 1989). Surface temperatures may reach as high as 24°C during extremely hot summers. Thermal stratification occurs from late June to September, and the thermocline is typically found between 10 and 24 m. Steep, rocky slopes characterize most of the shoreline, which is largely undeveloped. Littoral areas are limited and mostly characterized by having a very steep bottom, although some littoral areas are characterized by gradual or moderately sloping bottoms (found mostly in the northern end of the lake and in bays). The majority of fish habitat occurs in the pelagic area of the lake.

Historically, bull trout and northern pikeminnow *Ptychocheilus oregonensis* were the top two native predatory fish in Lake Pend Oreille (Hoelscher 1992). The historic native prey population was probably made up of mountain whitefish *Prosopium williamsoni*, pygmy whitefish *Prosopium coulterii*, slimy sculpin *Cottus cognatus*, suckers *Catostomus spp.*, peamouth *Mylocheilus caurinus*, and redside shiner *Richardsonius balteatus*, as well as juvenile salmonids (bull trout and westslope cutthroat trout *Oncorhynchus clarkii lewisi*). Sometime in the early 1920s, lake trout were introduced, and in 1941 Gerrard strain rainbow trout from Kootenay Lake, British Columbia, Canada were introduced. Presently, the top four predator fish are rainbow trout, bull trout, lake trout, and northern pikeminnow. Other fish that make up the remainder of the predator community, though found in low numbers, include northern pike *Esox lucius*, brown trout *Salmo trutta*, smallmouth bass *Micropterus dolomieu*, largemouth bass *Micropterus salmoides*, and walleye *Sander vitreus* (Hoelscher 1992). Introduced kokanee, which migrated down from Flathead Lake, Montana via the Clark Fork River in the 1930s (Maiolie et al. 2002), have become well established and are the principal forage item for rainbow trout, lake trout, and bull trout >415 mm (Vidergar 2000). Northern pikeminnow >305 mm utilize kokanee for about half of their total consumed food items (Vidergar 2000).
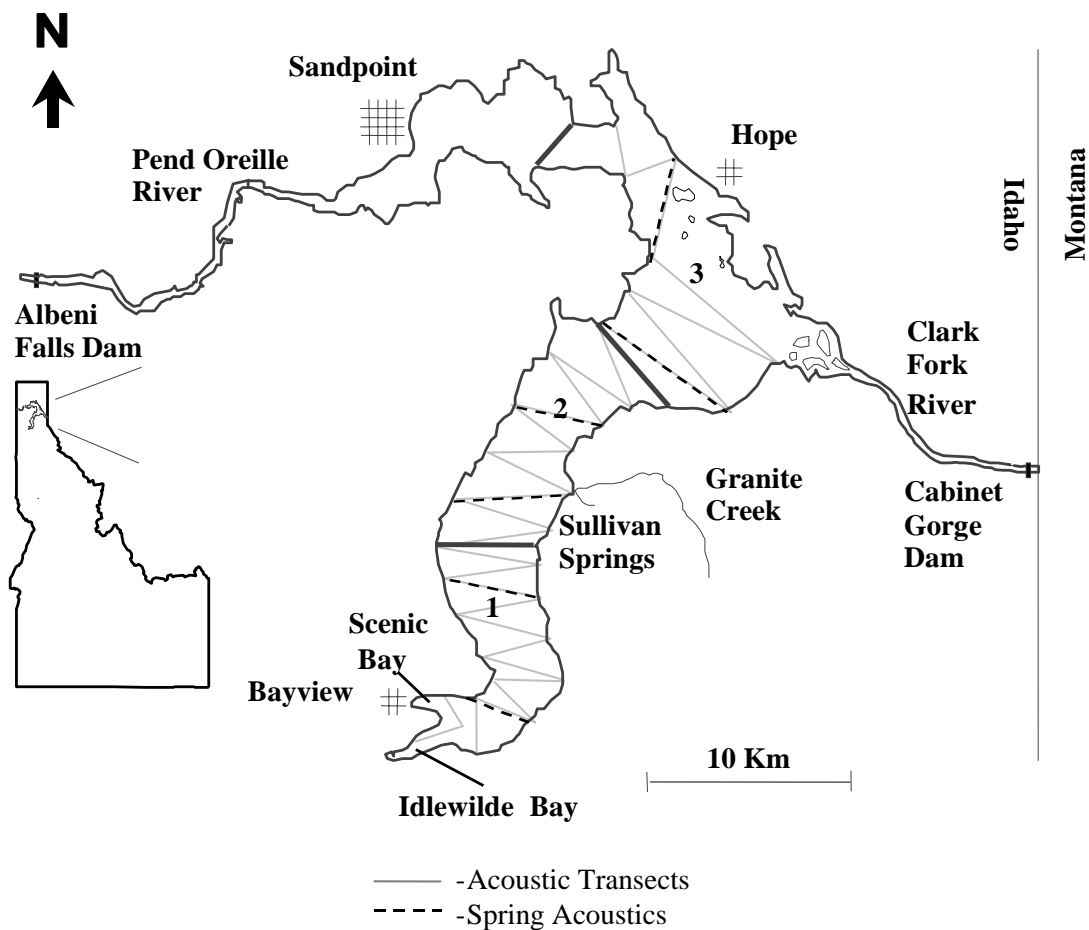
Figure 1. Map of Lake Pend Oreille, Idaho showing prominent landmarks and the three hydroacoustic sections marked by heavy grey line boundaries (sections 1, 2 and 3, are numbered from south to north). Sections 1, 2, and 3 contain 12, 10, and six transects, respectively. Transects for each lake section are numbered sequentially from south to north. Light grey lines mark the location of summer (August) hydroacoustic transects, and dashed lines represent spring (May) transects. Abundance estimates were made using August transects.

PROJECT GOAL

Lake Pend Oreille Predation Research aims to identify a functioning balance of predator (bull trout, rainbow trout, and lake trout) and prey (kokanee) populations so that kokanee populations improve to fishable levels and continue to provide bull trout with an ample supply of forage.

PROJECT OBJECTIVES

Objective 1.   Balance the pelagic predator and prey populations at a ratio of less than 1 kg predator to 6 kg prey. This ratio is a starting point for predator-prey balancing; other objectives will help to define this ratio more specifically for Lake Pend Oreille.

Objective 2.   Redefine the point of balance for predators and prey in Lake Pend Oreille where kokanee survival drops below 50% for any year class.

Objective 3.   Research and implement methods for the removal of rainbow trout and lake trout that will not impact bull trout. Adjust the predator:prey ratio until the balance point is reached.

Objective 4.   Minimize the competition between bull trout and other predatory fish. Kokanee survival rates over 50% would indicate forage is not in limited supply.

METHODS

Large Pelagic Fish Abundance and Depth Distribution

Hydroacoustic Methodology

We performed a lakewide hydroacoustic survey in August 2003 to determine day and night abundance and depth distribution of large pelagic fish. Large pelagic fish were defined as targets having returned echo strength larger than –33 dB (415 mm TL) (Love 1971), since they could be distinguished from the lake's pelagic kokanee population. Additionally, we utilized hydroacoustics to determine the pelagic depth distribution of fish >-45 dB (fish likely to be larger than age-0 kokanee) (Maiolie et al. 2002) during the spring of 2003. August surveys were conducted during summer stratification, because warmer water temperature might help keep predators deeper in the water column where they are more vulnerable to downlooking hydroacoustic techniques. Spring surveys were conducted on May 28 and 29. For all surveys, fish were classified into three groups (pelagic, benthic, or nearshore). A fish was considered pelagic if it was in water >70 m deep and further than 10 m from the bottom. If a fish was found in water <70 m deep and not within 10 m of the bottom, it was classified as nearshore (70 m was chosen because of the extreme steepness of the shoreline). A fish was considered benthic if it was found within 10 m of the bottom, regardless of depth. Density and population estimates were only made from the pelagic area.

A stratified systematic sampling design (Scheaffer et al. 1979) was used in our summer hydroacoustic survey to determine large pelagic fish abundance. Our survey design separated Lake Pend Oreille into three, nonoverlapping sections (sections 1, 2, and 3; see Figure 1). Within each section, we utilized a uniformly spaced zigzag pattern of transects as described by MacLennan and Simmonds (1992) (Figure 1). Transects were run from shoreline to shoreline and ranged in length from 3.4 km to 10.3 km. For our spring hydroacoustic survey, we sampled two transects in each lake section during day and night (Figure 1). The start and end points for each transect were located using a global positioning system (GPS). For all transects we utilized a 7.3 m boat and maintained a speed of approximately 1 m/s. For each sampling period (spring and summer), we collected water temperature profiles (surface to 60 m) in each lake

section using a calibrated Yellow Springs Instruments (YSI) Model 52 oxygen and temperature meter.

A Simrad EK60 scientific echo sounder equipped with a 120 kHz split beam transducer set to ping at 0.6 s intervals was used for the mobile hydroacoustic surveys. The transducer was located 0.5 m under the lake surface and placed in a downlooking position off the port side of the boat. Based on this position, the hydroacoustic beam would have a diameter of 1.2 m and 3.5 m at depths of 10 m and 30 m below the transducer, respectively. The echo sounder was calibrated annually for signal attenuation to the sides of the acoustic axis using Simrad's Lobe program.

Echoview software version 3.10.135.03 was used to locate fish targets from the hydroacoustic echograms (see Appendix A for Echoview settings). To distinguish potential pelagic fish >415 mm, hydroacoustic traces (a single returned echo from a fish) were only examined if they were: 1) >–39 dB (smaller than –33 dB but will allow for signal averaging to increase the number of targets), 2) the returned echo length at 6 dB below the peak value was between 30% and 180% of the original pulse, 3) the correction value returned from the transducer gain model did not exceed a two-way maximum gain compensation of 6.0 dB (therefore, includes all targets within the 3 dB beam width), and 4) the maximum standard deviation of the minor and major axis angles was less than 0.6 degrees. Targets were not filtered based on their beam angles, but instead we used the maximum gain compensation to filter out targets that were outside of the 6.8° cone. Returned echo traces from fish were averaged, and only targets with a mean target strength >-33 dB (>415 mm) were included as potential predatory fish. For spring surveys we used similar techniques but used targets >-45 dB (97 mm) as our cutoff point.

Density and Population Estimates

During our August 2002 hydroacoustic survey, we located two different groups of pelagic fish >-33 dB (Bassista and Maiolie 2004); based on these findings we determined density and population estimates using two different methods for our August 2003 hydroacoustic data. For the first method (All Fish Method) we utilized all pelagic echo traces that averaged >-33 dB from all transects. This gave us a total estimate of all pelagic fish >415 mm found throughout the hydroacoustic survey area and water column (as done in 2002). Conclusions from Bassista and Maiolie (2004) suggest that by estimating large pelagic fish from the entire water column within the hydroacoustic survey area (All Fish Method), the estimate may be comprised of nonpredators (e.g. lake whitefish). For the second method (Shallow Method) we only used pelagic echoes >-33 dB that were found in ≤30 m of water and not aggregated with similar sized fish and assumed we were mostly detecting rainbow trout.

Large pelagic fish density (fish/ha) for each transect was calculated by dividing the number of large pelagic fish by the area sampled at the depth of the fish for each method (i.e., for both the All Fish Method and Shallow Method). Area was calculated by multiplying the number of pings on a transect by the area of a circle at the depth of the fish with a 6.8° cone. Densities were summed (vertically) when more than one large fish was found on a transect. Density estimates were log transformed (log [x+1]) and then averaged for each lake section to obtain a geometric mean density per lake section. An overall mean density estimate was determined for the All Fish Method only during the night. Both day and night density estimates were made for the Shallow Method.

A population estimate was determined for each lake section by taking the geometric mean density (fish/ha) for each section and multiplying it by each section's area (ha) beyond the lake's 70 m contour line (i.e., areas with depths shallower than 70 m were excluded). Lake section population estimates were added together to determine a lakewide population estimate. Population estimates were made for the nighttime All Fish Method and the day and night Shallow Method.

A 90% confidence interval (CI) was calculated for our population estimates using the following equation for systematic stratified sampling (Scheaffer et al. 1979):

$$\overline{X} \pm t_{n-1}^{90} \sqrt{\frac{1}{N_{total}^2} \sum_{i=1}^{3} N_i^2 \left(\frac{N_i - n_i}{N_i} \right) \frac{s_i^2}{n_i}}$$

where $\overline{X}$ = mean fish/ha (log transformed),
t = Student's t value,
N = total number of possible transects,
s = standard deviation, and
n = actual number of transects.

Once we calculated the 90% CI, we converted the mean density and CI back using exponentials (see Appendix B for an example of calculating a CI for the nighttime Shallow Method) and calculated a 90% CI for our lake-wide population estimates. We compared nighttime population estimates made during the summer of 2002 (Bassista and Maiolie 2004) with our 2003 All Fish Method to compare the difference between the two hydroacoustic processing methods (echo integration in 2002 and echo counting in 2003). We also compared the day and night lakewide population estimates as determined from the Shallow Method.

Large Pelagic Fish Biomass

A lakewide biomass estimate of pelagic fish >415 mm was calculated to determine the biomass ratio (kg) of large pelagic fish to pelagic prey (kokanee). To achieve a large pelagic fish biomass estimate (assuming the fish are mostly rainbow trout), we used the nighttime population estimate from the Shallow Method (see methods under Density and Populations Estimates) to eliminate the uncertainties of including lake whitefish in our estimate and because nighttime hydroacoustic surveys on Lake Pend Oreille record more fish (Bassista and Maiolie 2004). This did not eliminate the uncertainties of including pelagic bull trout or lake trout, but we assumed most of those fish were in nearshore and benthic areas. Length data were obtained by converting the nighttime hydroacoustic target strength measurement (dB) of fish processed during August 2003 into fish length (mm) using the following equation from Love (1971):

$$TS = 19.1 \, \text{Log} \, L + 0.9 \, \text{Log} \, \lambda - 34.2$$

where TS = target strength (dB),
L = fish length in ft, and
λ = acoustic wavelength in ft.

We then converted fish length to weights using Irving (1986) rainbow trout equation:

$$W = 0.000126 \text{ X } L^{3.385}$$

where W = weight (lbs) and
       L = length (inches).

Fish weights were then converted to kg for reporting. Large fish biomass was then calculated by multiplying the mean density (fish/ha) times the number of hectares in the lake beyond the lake's 70 m contour (21,332.1 ha) times the mean weight of the shallow group of pelagic fish.

Pelagic Prey and Large Pelagic Fish Depth Distribution

To examine the day and night depth distribution of kokanee ages 1-4 (prey) and large pelagic fish (potential predators) during the spring, we created scatter plots of fish depth and size for all fish echoes >-45 dB (this was the cutoff between age-0 and age-1 kokanee in Lake Pend Oreille) (Maiolie et al. 2002). Prey depth distribution was plotted for each day and night transect during our spring (May 28 and 29) 2003 hydroacoustic survey (see Figure 1 for transect locations). Large pelagic fish (fish echoes >-33 dB) were also graphed using a scatter plot, and echoes were combined from all transects (day and night) into one graph. Fish depth was plotted with fish size.

The depth distribution of large pelagic fish (>-33 dB) at night was examined during the summer of 2003 (August) using a scatter plot of fish depth and distance from bottom. Fish were classified as either being found in aggregations with other fish or being found alone (solitary).

Predator Collection and Sonic Transmitter Insertion

Transmitter Calibration

Depth-sensitive sonic transmitters (Sonotronics DT-97-L transmitters) were used to examine the habitat use of predators to help identify fish recorded with hydroacoustic gear. Each transmitter (sonic tag) measured 86 mm in length, 18 mm in diameter, and weighed 7.5 g in water. Transmitter battery life was approximately 12-24 months and had a detection range of up to 3 km. Each transmitter was uniquely coded, and five transmitters emitted a sonic signal at 74 kHz, five at 75 kHz, five at 76 kHz, and five at 77 kHz. Each transmitter was factory calibrated for depth and had a guaranteed accuracy range of ±2% of full-scale pressure (psi). Each tag had a full-scale pressure measurement of 356.0 psi (accuracy range of ±4.2 m).

In order to determine how accurate the transmitters (tags) were, we conducted a calibration test. Each tag was lowered to 15, 30, and 45 m using a downrigger with a marked cable and a 3.6 kg lead ball connected to the end of the cable. When the tag reached its test depth, we measured the transmitter's ping interval using a directional hydrophone (Sonotronics model USR-96 receiver). Measurements were collected from a boat that was located 100 to 200 m away from the transmitter. Actual tag depth was plotted against the measured tag depth, and linear regression was used to determine how well the two depths correlated. If the transmitted tag depth differed from the known tag depth by >±4.2 m, the tags were sent back to the manufacturer for recalibration.

Tagging Procedures

Predatory fish used for tracking were collected and implanted with sonic transmitter during May and June 2003 and in February 2004. Fish >1,360 g were collected in 2003 using large mesh (>100 mm stretch) gillnets and by angling. Fish collected in 2004 were captured using large trap nets (see Peterson and Maiolie 2004 for description). Fish in good condition were held in a shaded suspended net pen (depth approximately 2.5 m) for ≥12 h prior to surgical implants of sonic tags.

Sonic transmitters were soaked in a diluted iodine solution (approximately 30%) for at least 10 min before insertion. Fish were removed from our suspended net pens and checked for any signs of stress that would deter us from performing surgery. Fish were anesthetized until a complete loss of equilibrium and swimming motion was observed (typically 4-5 min). Anesthetized fish were transferred to a surgery table, dorsal side down, where the anesthetic solution was continuously pumped over the gills. Immediately after the fish was placed on the surgery table, the cutting area was wiped with an iodine solution, and a 4-5 cm incision was made parallel to the mid ventral line, anterior to the pelvic girdle, and below the posterior end of the pectoral fin. Thumb forceps were used to ensure the scalpel did not damage the viscera while making the incision. The sonic transmitter was gently inserted posteriorly toward the pelvic girdle. A small amount of liquid tetracycline was applied to the incision before suturing. The incision was closed using four separate monofilament sutures (Ethicon Prolene 2-0, 45 cm, cutting FS polypropylene suture). The area was blotted dry using a sterile gauze pad, a small amount of tissue adhesive (Nexaband® Liquid-formulated cyanoacrylate) was applied to the closed incision, and care was taken not to get the adhesive in the incision. The fish was then immediately placed in a freshwater live well to recover. After the fish retained its equilibrium and swimming motion, it was placed back into a suspended net pen. The fish were held for an additional 24 h before being released. Most fish were released at their original capture site.

Predator Sonic Tracking

Due to concerns about transmitter detection range above and below a thermocline, we tested the range performance of two different types of hydrophones during lake stratification. Our standard directional hydrophone (Sonotronics model DH-4) was tested alongside an omnidirectional hydrophone (Sonotronics model SH-1). We utilized the same output-power depth-transmitter as in our fish, but the test transmitter (non-depth sensing) did not provide a ping interval to translate into a depth measurement. The transmitter was stationed at three different test scenarios designed to mimic the locations of predator fish found above and below the thermocline. For test 1, we positioned the transmitter at 4.5 m within 30.5 m from shore (to mimic northern pikeminnow locations). For test 2, we put the transmitter down to 30.5 m and positioned the transmitter so it was within 10 m of the bottom (to mimic benthic bull trout and lake trout locations). For test 3, we stationed the transmitter at 30.5 m over water >122 m deep (to mimic pelagic bull trout and lake trout locations). For each test, we lowered the directional hydrophone, which was attached to a wooden pole, to 2.5 m and visually pointed it towards the transmitter (water clarity allowed for this). We attached a small weight to the omnidirectional hydrophone and lowered it to 2.5 m and to approximately 24.0 m (thermocline was between 14 and 18 m). For each test we only recorded the maximum distance we could hear the transmitter. From this information, we knew how far we could travel between listening locations while searching for tagged fish.

Predator sonic tracking was performed during spring (March 21-June 20) and summer (June 21-September 22) 2003 to determine habitat use of rainbow trout (spring only), lake trout, bull trout, and northern pikeminnow (summer only) to help identify hydroacoustic targets >415 mm found on spring and summer echograms. Sonic tagged lake trout and bull trout were tracked from September 23, 2003 to March 19, 2004 to determine habitat use and to monitor their movements in relation to the concurrent trap net fishery research project, which started on September 30, 2003 and continued to the end of March 2004 (see Peterson and Maiolie 2004 for trap net results). Due to safety and concerns about equipment performance (i.e., hydrophone range is greatly reduced in wavy/noisy environments), tracking effort was limited to days when the lake surface was calm. We tracked fish only during the day and at night. Crepuscular hours were avoided since we did not conduct hydroacoustic surveys during that time period. All tracking was conducted from a 6.3 m boat using a directional hydrophone (Sonotronics model DH-2) and portable receiver (Sonotronics model USR-96). Once a fish was located, we made every attempt to get as close to it as possible before recording a habitat observation. We assumed we were directly over the fish when the transmitter signal volume was equal through 360° of hydrophone rotation. At each location we recorded the following data: time of day, date, general location, latitude and longitude, transmitter ID, transmitter ping interval (depth of fish), lake depth under fish, distance from nearest shore, and temperature at fish depth. When a fish was located, we either made one habitat observation and then moved on to search for another fish, or stationed ourselves near the fish and made one observation every 1 h for up to 4 h, depending on weather conditions and/or time constraints. Once an observation was complete, a fish was classified into one of our predefined habitat types: pelagic, nearshore, or benthic (see methods for Pelagic Predator Abundance and Depth Distribution for habitat type description). Fish location (position) was determined by using a GPS unit, and distance from shore was estimated either by a digital navigation chart of Lake Pend Oreille (Nobeltec Visual Navigation Suite 6.0) loaded on a laptop computer and connected to the boats GPS or by using radar (Furuno 1721 Mark-2). Water temperature of the fish was acquired using a dissolved oxygen and temperature meter (YSI model 52) to a lake depth of 60 m (maximum cord length). If a fish was found below 60 m, we used the lake temperature at 60 m. Lake depths were determined by an echo sounder (Furuno FCV-582L).

Hydroacoustic Community Identification

Pelagic fish species composition (all sizes of fish) was determined by conducting standardized midwater trawling in Lake Pend Oreille from August 22 to August 29. Detailed sampling equipment and procedures were described by Rieman (1992) and Maiolie et al. (2002). Trawling was only performed throughout the vertical distribution of kokanee (minimum depth = 12.2 m and maximum depth = 39.6 m) based on the location of pelagic fish schools located with an echo sounder (Furuno FCV-582) during trawling. Fish were either identified in the field or put on ice and identified in the laboratory.

Based on hydroacoustic data collected during August 2002, Bassista and Maiolie (2004) indicated a group of pelagic fish >-33 dB in size (i.e., >415 mm) were present in the northern portion of Lake Pend Oreille. This group was thought to be either pelagic predators or pelagic lake whitefish because the targets were too large to be kokanee. Upon completion of our August 2003 hydroacoustic survey, we recorded a group of fish suspended 40 to 60 m deep in an area of depth exceeding 100 m, similar in depth and location as the group detected in August 2002. We suspended neutrally buoyant monofilament gill nets (6.0 m deep X 60.0 m long) between 40 and 60 m water depths near where the pelagic group was observed, during nighttime hours. The gill nets were composed of two 6.0 m long panels of the following mesh sizes: 50.8 mm,

76.2 mm, 101.6 mm, 127.0 mm, and 152.4 mm, randomly placed throughout the net. Soak time for each net was between 2 and 10 hours.

To help determine if lake trout or bull trout were included in the Shallow Method population estimate (see Density and Population Estimates methods), we monitored the habitat use of bull trout and lake trout by sonic tracking. By collecting detailed location information (e.g., fish depth, fish distance from bottom, etc.) on our telemetered fish, we were able to integrate tracking data with hydroacoustic data to help identify unknown acoustic echoes. Nighttime tracking data was graphed by individual species with nighttime hydroacoustic echo returns using a scatter plot of fish/target depth and fish/target distance from bottom.

Predator and Prey Ratio

To assess the potential pelagic predator impact on the kokanee population, we compared the hydroacoustic derived biomass ratios of large pelagic fish >-33 dB to kokanee (prey) during August 2003 (predator [kg]:prey [kg]). We assumed that our large pelagic fish biomass estimate was predominantly comprised of rainbow trout >415 mm. Therefore, a comparison of a portion of the rainbow trout biomass could be made to the kokanee biomass. Maiolie et al. (2004) determined a total biomass estimate for all sizes of kokanee. Kokanee population estimates were made from the same echograms as the large pelagic fish estimate, allowing for a direct comparison of potential predator to kokanee prey.

RESULTS

Large Pelagic Fish Abundance and Depth Distribution

Density, Population Estimates, and Biomass

Population estimates of fish >-33 dB detected by hydroacoustics throughout our sample area were significantly higher in 2002 compared to 2003. The nighttime lakewide population estimate of large pelagic fish in August 2003, as determined by echo counting, was 18,784 (11,898 to 27,129 ± 90% CI). This estimate was much lower compared to our estimate in August 2002, as determined by echo integration, of 39,044 (28,651 to 51,604 ± 90% CI). During August 2003 mean density estimates of large pelagic fish were highest in section 3 (0.4 fish/ha) followed by section 1 (0.28 fish/ha) and section 2 (0.09 fish/ha). The first and third highest density estimates were found in section 3 on transects 3-6 and 3-5, respectively. Density estimates were lower in sections 2 and 3 but higher in section 1 between 2002 and 2003 (Table 1).

Our nighttime Shallow Method population estimate of 11,733 (7,007 to 17,251 ± 90% CI) was significantly higher than our daytime population estimate of 2,965 (101 to 6,213 ± 90% CI). Hydroacoustic fish targets were detected on four of 28 transects during the day compared to 15 of 28 transects during the night (Table 2). Mean nighttime density estimates where highest in section 1 (0.28 fish/ha), followed by section 3 (0.21 fish/ha). Section 2 had the lowest number of transects that detected targets (3 transects) and had the lowest mean density estimate (0.07 fish/ha). Large pelagic fish from –33 dB to –31 dB (415 mm to 530 mm) (lengths converted from Love 1971) made up the majority (72%) of the size classes found in our large pelagic fish population estimate (Figure 2).

We detected 22 hydroacoustic targets ranging in weight from 0.82 kg to 15.85 kg (mean = 2.60 kg) during our 2003 survey (Table 3). Total biomass of large pelagic fish >415 mm found in water depths ≤30 m and not aggregated with other fish (Shallow Method) was 30.5 tonnes in August 2003.

Table 1. Nighttime large pelagic fish (>-33 dB) density (fish/ha) estimates for each hydroacoustic transect using the All Fish Method performed during August 2002 and 2003. Section means were based on log transformations (log [x+1]). Transects for each lake section are numbered sequentially from south to north (see Figure 1).

	Section 1			Section 2			Section 3	
Transect #	2002 (fish/ha)	2003 (fish/ha)	Transect #	2002 (fish/ha)	2003 (fish/ha)	Transect #	2002 (fish/ha)	2003 (fish/ha)
1	0.08	0.00	1	0.00	0.00	1	0.52	0.29
2	0.00	0.30	2	0.00	0.00	2	0.25	0.27
3	0.13	0.50	3	0.40	0.00	3	0.55	0.06
4	0.31	0.57	4	0.35	0.40	4	0.41	0.24
5	0.00	0.00	5	0.14	0.00	5	0.67	0.61
6	0.45	0.00	6	0.60	0.10	6	1.11	0.94
7	0.00	0.00	7	0.64	0.25			
8	0.31	0.39	8	0.82	0.25			
9	0.00	0.32	9	0.81	0.00			
10	0.12	0.79	10	0.64	0.00			
11	0.18	0.55						
12	0.00	0.00						
Section mean	**0.13**	**0.28**	**Section mean**	**0.44**	**0.09**	**Section mean**	**0.59**	**0.40**

Table 2. Night and day large pelagic fish density (fish/ha) estimates as determined by the Shallow Method during August 2003. Section means were based on log transformations (log [x+1]). Transects for each lake section are numbered sequentially from south to north (see Figure 1).

	Section 1			Section 2			Section 3	
Transect #	Day (fish/ha)	Night (fish/ha)	Transect #	Day (fish/ha)	Night (fish/ha)	Transect #	Day (fish/ha)	Night (fish/ha)
1	0.72	0.00	1	0.00	0.00	1	0.00	0.29
2	0.00	0.30	2	0.00	0.00	2	0.00	0.27
3	0.00	0.50	3	0.23	0.00	3	0.00	0.06
4	0.00	0.57	4	0.00	0.40	4	0.00	0.24
5	0.39	0.00	5	0.56	0.00	5	0.00	0.00
6	0.00	0.00	6	0.00	0.10	6	0.00	0.44
7	0.00	0.00	7	0.00	0.25			
8	0.00	0.39	8	0.00	0.00			
9	0.00	0.32	9	0.00	0.00			
10	0.00	0.79	10	0.00	0.00			
11	0.00	0.54						
12	0.00	0.00						
Section mean	**0.09**	**0.28**	**Section mean**	**0.08**	**0.07**	**Section mean**	**0.00**	**0.26**
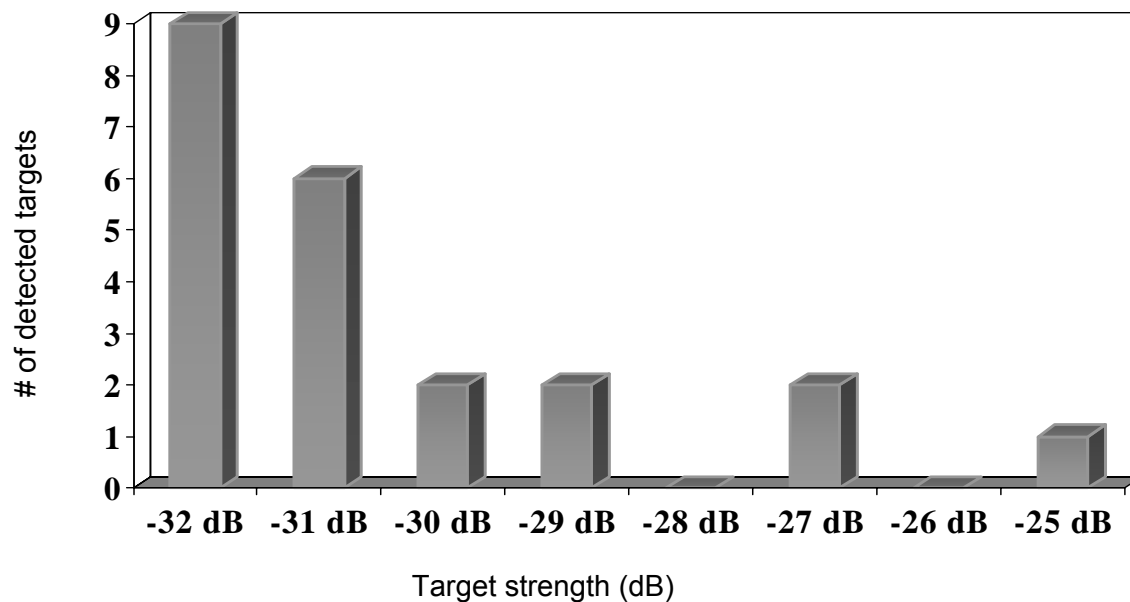
Figure 2. Frequency distribution of the target strengths of large pelagic fish used in the Shallow Method population estimate in Lake Pend Oreille during August 2003.

Table 3. Estimated weights of large (>-33 dB) pelagic (water >70 m deep) fish that were at depths <30 m in Lake Pend Oreille, Idaho in August 2003. Weights were based on Irving's (1986) length-weight regression for Kamloops rainbow trout.

Fish No #	Lake Section	Target Strength (dB)	Length (mm)	Weight (kg)
1	1	-32.8	520	1.57
2	1	-29.0	670	3.70
3	1	-27.8	770	5.92
4	1	-31.4	500	1.37
5	1	-31.5	495	1.33
6	1	-31.1	520	1.57
7	1	-32.1	460	1.04
8	1	-31.3	505	1.42
9	1	-31.8	480	1.20
10	1	-32.6	435	0.86
11	1	-31.2	515	1.52
12	1	-30.9	533	1.70
13	2	-31.9	470	1.11
14	2	-32.5	440	0.89
15	2	-32.3	450	0.96
16	2	-32.5	440	0.89
17	3	-30.7	545	1.84
18	3	-25.4	1030	15.85
19	3	-29.8	610	2.69
20	3	-32.7	430	0.82
21	3	-27.1	840	7.95
22	3	-32.5	440	0.89

Mean weight per fish = 2.60 kg

Pelagic Prey and Large Pelagic Fish Depth Distribution

Spring—Pelagic prey (kokanee ages 1-4) displayed an upward vertical migration at night while staying in deep water during the day. During the day, two groups of prey fish were observed. The shallow group was in water depths between 40 and 80 m, while the deeper group occupied the 100 to 160 m depth range. During the night a group of prey fish moved upward near the surface and suspended in 0 to 30 m of water, while a deeper group stayed between 40 and 80 m. Prey fish found between 40 and 80 m were located on both day and night transects (see Figure 3 for an example of one day and one night transect).

Fourteen large pelagic fish targets >-33 dB were found from 12 hydroacoustic transects (6 day and 6 night). Only two targets were found during the day. These targets were located in the middle and southern section of Lake Pend Oreille in water depths <65 m. All nighttime targets were found in the northern most spring transect in water depths between 25 and 60 m (Figure 4).

Summer—During the summer of 2003, we detected two groups of large pelagic fish from a nighttime hydroacoustic survey (Figure 5). The shallower group consisted of 22 solitary targets located at depths between 10 and 30 m. This group was found throughout the lake in a mean water depth of 19.4 m (SD = 4.4) and mean temperature of 10.8°C (SD = 2.6). The second deeper group consisted of 19 targets and was found at depths between 30 and 70 m. This group was predominantly located in the northern portion of the lake in a mean water depth of 51.2 m (SD = 11.9) and a mean temperature of 5.7°C (SD = 0.6). A majority of this deeper group was found in aggregations of other fish.
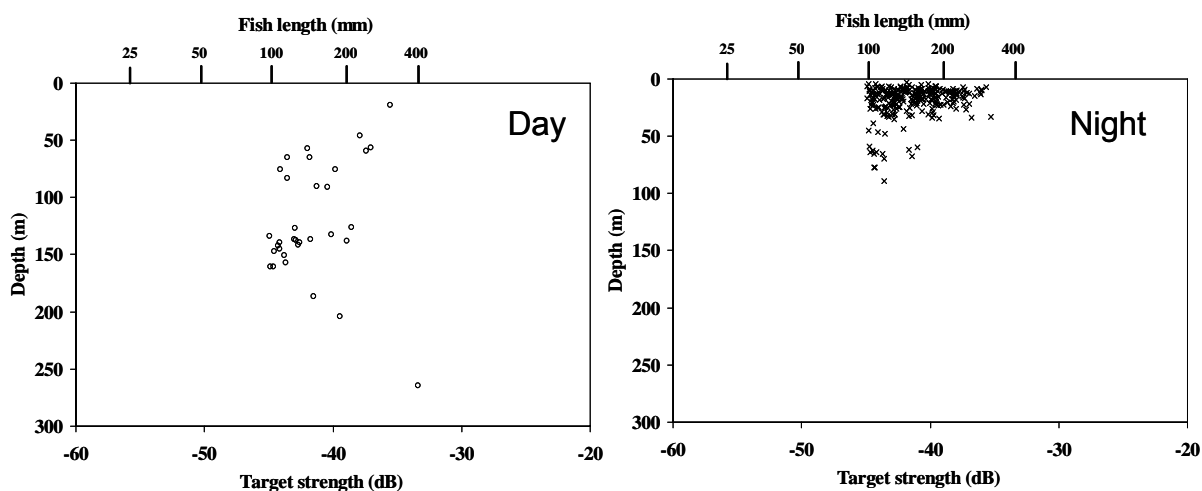
Figure 3.   Day and night depth distribution of hydroacoustic targets >-45 dB (likely kokanee age 1-4) sampled from transect 3-1 during a spring 2003 (May 28 and 29) hydroacoustic survey.

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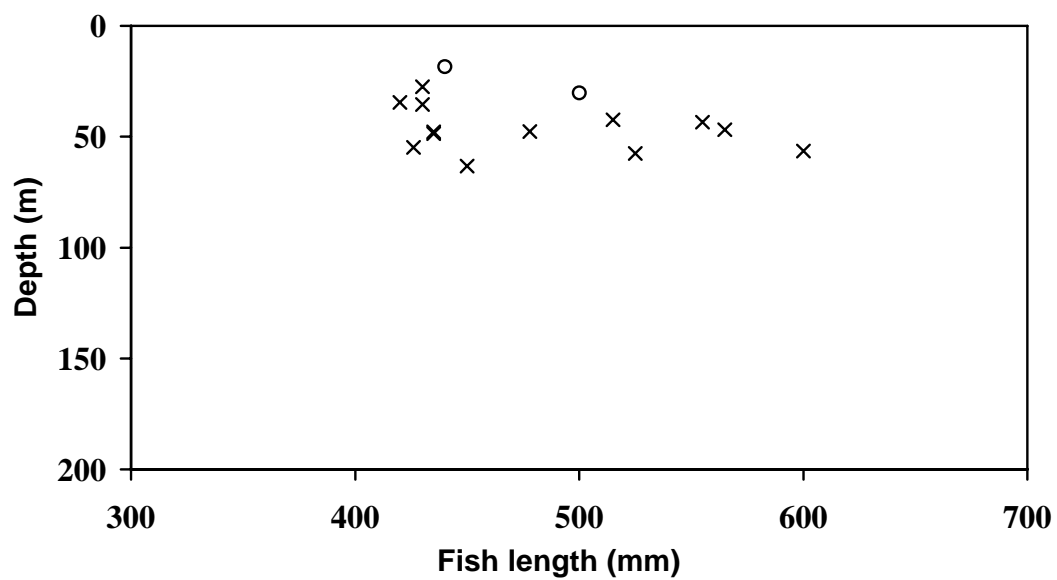
Figure 4. Day (O) and night (X) depth distribution of all large pelagic fish >-33 dB found from a spring 2003 (May 28 and 29) hydroacoustic survey.
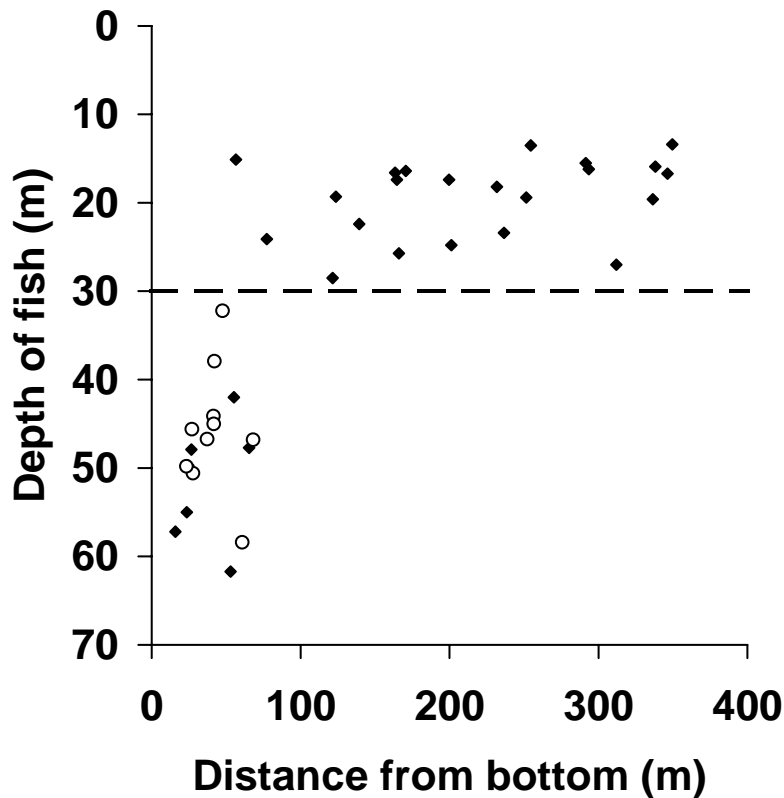
Figure 5. Hydroacoustic nighttime depths and distances from the lake bottom for large targets (>-33 dB) in the pelagic area (water >70 m deep) of Lake Pend Oreille, Idaho in August 2003. Open circles represent fish that were in an aggregation of similar sized fish. Solid diamonds were solitary fish and considered potential pelagic predators. Dotted line at the 30 m depth illustrates our division between the shallow and deep targets.

Predator Tagging and Tracking

Transmitter and Hydrophone Performance

Prior to transmitter insertion, we tested the performance of 20 transmitters and our receiver on April 24, 2003. Three depths were tested, 15, 30, and 45 m, and transmitted depths ranged from 11.9 to 15.5 m, 26.2 to 31.1 m, and 41.8 to 46.9 m for each test interval, respectively. Transmitted depths were highly correlated to known depths (r^2 = 0.9946) and no transmitter deviated from the manufactures guaranteed accuracy range.

On August 8, 2003, we determined the maximum range our hydrophones could detect a sonic transmitter signal above and below a thermocline. The thermocline during testing was located between 14 and 18 m. The maximum range that our directional hydrophone could detect a transmitter signal was 1.66 km for test scenario 1 (tag @ 4.5 m within 30.5 m from

shore) and 1.85 km for test scenario 2 (tag @ 30.5 m within 10 m off bottom) and test scenario 3 (tag @ 30.5 m over depths >122 m). The maximum range that we could detect transmitters using the omnidirectional hydrophone was 1.85 km for all hydrophone depths and test scenarios. Based on these results, we continued using the directional hydrophone during the summer tracking period due to the advantage of knowing the direction of the fish. Distance between listening stations was set at 1.5 km.

Tagging Effort

From May 9, 2003 to June 11, 2003, we performed 17 surgeries to implant transmitters on one rainbow trout, six bull trout, seven lake trout (all fish >2,100 g), and three northern pikeminnow (>1,361 g) (Table 4). Of these 17 surgeries, 14 fish (six bull trout, six lake trout and two northern pikeminnow) survived. Three of the non-surviving fish (one lake trout, one northern pikeminnow, and one rainbow trout) either died or expelled their tag within two weeks of their release. One bull trout either died or expelled its tag within 100 m of a public boat ramp during the summer (August 23, 2004). One lake trout was captured in a trap net during November and was sacrificed so we could examine the surgery wound for healing. The wound was completely healed with no signs of internal or external tissue damage; only a scar was present. From February 16 to 24, 2004, we performed five surgeries on bull trout (>3000 g) that were collected by the large trap net fishery.

Table 4.   Fish implanted with sonic transmitters. Rainbow trout (Rbt), lake trout (Lkt), bull trout (Blt), and northern pikeminnow (Pkm) were captured either by hook and line (H and L), monofilament gillnets (gillnet), or large trap nets (trap net).

Species	TL (mm)	Wgt (g)	Capture method	Date	Status	Tag ID
Lkt	830	6690	gillnet	5/9/03	Died after release	4-4-5-7
Lkt	950	6917	gillnet	5/9/03	Tracked	4-4-6-6
Blt	702	3719	H and L	5/9/03	Not located since release	4-4-4-4
Lkt	705	3402	gillnet	5/13/03	Not located after 6/17/03	4-4-6-7
Pkm	565	1814	gillnet	6/3/03	Not located after 6/16/03	4-5-5-5
Lkt	770	4717	gillnet	6/3/03	Tracked	4-4-5-7
Lkt	700	3402	gillnet	6/3/03	Captured in trap net on 11/10/03*	4-4-6-5
Lkt	640	2268	gillnet	6/3/03	Tracked	4-4-7-5
Rbt	685	3289	gillnet	6/5/03	Died after release	4-5-7-6
Lkt	721	3447	gillnet	6/5/03	Tracked	4-4-7-7
Blt	645	2268	gillnet	6/5/03	Tracked	4-4-4-5
Blt	671	5216	gillnet	6/6/03	Not located after 9/9/03	4-4-5-6
Pkm	571	2041	gillnet	6/10/03	Died after release	7-7-7-7
Blt	640	2155	gillnet	6/10/03	Not located after 9/4/03	4-4-4-7
Blt	712	3538	gillnet	6/10/03	Tracked	4-4-4-6
Blt	642	2495	gillnet	6/11/03	Died or shed tag on 8/23/03	4-4-5-5
Pkm	NA	1380	H and L	6/27/03	Tracked	4-5-6-6
Blt	740	4237	trap net	2/17/04	Tracked	5-5-6-7
Blt	695	3402	trap net	2/17/04	Tracked	4-4-7-6
Blt	725	3969	trap net	2/18/04	Tracked	4-5-6-5
Blt	670	3062	trap net	2/23/04	Tracked	4-5-5-6
Blt	780	4976	trap net	2/24/04	Tracked	4-5-7-6

*This fish was sacrificed to examine the internal condition of the fish several months after surgery.

Tracking Effort

Spring—Our 2003 spring tracking effort began on March 21 and concluded June 20. We performed 25 separate tracking sessions during this time, and each session lasted approximately 8 h. During this 13-week period, we tracked fish every week except for the 6th and 8th weeks. Most of our effort was made during daylight hours (78%) compared to nighttime hours (22%). We located nine lake trout (four of which were tagged in the winter of 2002-2003), three bull trout, and three rainbow trout (tagged in 2002). Eighty-three percent of the observations were from lake trout (Table 5). In total, we made 118 habitat observations on these fish.

Summer—Our 2003 summer tracking effort began on June 21 and concluded September 22. We performed 29 separate tracking sessions during this time, and each session lasted for approximately 8 h. During this 14-week period, we tracked fish every week except for the 3rd, 4th, and 13th weeks. A majority of our effort was made during daylight hours (67%) compared to nighttime hours (33%). We located nine lake trout (four of which were tagged in 2002), five bull trout, and one northern pikeminnow. In total, we made 246 habitat observations; 47% of the observations were made on lake trout, 44% on bull trout, and 9% on the northern pikeminnow (Table 5).

Fall and Winter—Our fall and winter tracking effort began on September 23, 2003 and concluded March 19, 2004. We performed 20 separate tracking sessions during this time, and each session lasted for approximately 8 h, though many sessions were cut short due to adverse weather conditions. During this 26-week period, we performed one tracking session in September, seven in October, five in November, zero in December, three in January, two in February, and two in March. All of our effort was during daylight hours. We located nine lake trout, four of which were tagged in 2002, and six bull trout, two of which were tagged and released after February 17, 2004. In total, we made 80 habitat observations; 78% of the observations were made on lake trout and 12% on bull trout (Table 5).

Table 5.   Sonic tracking effort for all seasons during 2003. A tracking session typically lasted from 6 to 8 h. Fish species are abbreviated as: lake trout = Lkt, rainbow trout = Rbt, bull trout = Blt, and northern pikeminnow = Pkm. Parentheses () next to fish name indicate the total number of fish tracked for each season.

	# of tracking sessions		# of habitat observations			% tracking effort	
	Day	Night	Day	Night	Species	Day	Night
Spring	19	6	70	48	Lkt (9)	42%	41%
					Rbt (2)	13%	0%
					Blt (3)	4%	0%
					Pkm (0)	0%	0%
Summer	19	10	138	108	Lkt (9)	28%	19%
					Rbt (0)	0%	0%
					Blt (5)	23%	21%
					Pkm (1)	5%	4%
Fall/Winter	20	0	80	0	Lkt (9)	78%	0%
					Rbt (0)	0%	0%
					Blt (6)	22%	0%
					Pkm (0)	0%	0%

Bull Trout Habitat Use

Spring—Five daytime habitat observations were made for bull trout in spring. During late spring (after mid June), bull trout were exclusively found in nearshore benthic areas (Figure 6). Bull trout were located at a mean depth of 23 m (SD = 9, range = 15-37 m) and in temperatures <10.0°C (mean = 7.4°C, SD = 2.1, range = 5.0-9.9°C). They were located at a mean distance offshore of 140 m (SD = 65, range = 50-200 m).

Summer—During the summer we recorded 107 habitat observations on five bull trout. Over half (52%) of these observations were made during daylight hours. Bull trout utilized all three of our predefined habitat types (i.e., benthic, nearshore, and pelagic) but were predominately found in benthic (66%) and nearshore (25%) areas (day and night data combined) (Figure 7).

Bull trout located in benthic areas were found at similar mean depths during day (19 m, SD = 8, range = 10-46 m) and night (19 m, SD = 3, range = 14-29 m). They also utilized similar mean temperatures during day (10.6°C, SD = 2.5, range = 5.5-15.8°C) and night (9.8, SD = 1.7, range 7.2-12.5°C). Benthic bull trout were located similar distances from shore during the day (mean = 84 m, SD = 77, range = 20-370 m) and night (mean = 69 m, SD = 55, range 15-185 m).

Bull trout located in nearshore areas during the summer were found in shallower mean depths during the day (12 m, SD = 4, range 5-18 m) compared to night (17 m, SD = 4, range 4-27 m). Mean temperature use was similar between day (12.8°C, SD = 5.0, range 6.0-21.1°C) and night (11.3°C, SD = 2.7, range 8.5-21.1°C) as was mean distance from shore between day (53 m, SD = 37, range = 15-100 m) and night (55 m, SD = 40, range 15-100 m).

Pelagic bull trout were located in similar mean depths during the day (17 m, SD = 4, range = 8-22 m) and night (15, SD = 2, range 13-17 m). Mean temperature use was also similar between day (9.9°C, SD = 2.2, range = 5.6-8.2°C) and night (10.0°C, SD = 0.07, range = 9.9-10.0°C). Pelagic bull trout during day and night were found from 300 to 4,000 m offshore and in water depths exceeding 150 m.

Fall and Winter—We did not locate any of our sonic tagged bull trout until the end of October 2003. In November, we located two bull trout and monitored their movements and habitat use during November 2003 and January, February, and March 2004. We located three additional bull trout in March 2004 that were tagged and released after February 17, 2004. All of our fall and winter habitat observations were made during daylight hours.

During the fall and winter period, 60% of our bull trout habitat observations were from nearshore benthic areas, while the rest of the observations were from open water pelagic areas (Figure 6). Benthic bull trout utilized a mean depth of 26 m (SD = 18, range = 8-62 m) and a mean temperature of 5.5°C (SD = 1.6, range = 4.1-8.0°C). Benthic bull trout were found from 25 m to 370 m offshore. Pelagic bull trout tended to use shallower mean depths (20, SD = 8, range = 8-34 m) than benthic bull trout. Mean temperature use of benthic bull trout (5.2°C, SD = 2.1, range = 4.4-10.0°C) was similar to pelagic fish, but pelagic fish were found much further offshore (mean = 1,696 m, SD = 1,355, range = 300-3,704 m) than benthic fish.

Lake Trout Habitat Use

Spring—During the spring season we made 97 habitat observations of lake trout, slightly more than half of which (51%) were made during daylight hours. Lake trout utilized all three of our predefined habitat types (i.e., benthic, nearshore, and pelagic) but were predominantly found in benthic and nearshore areas during day (88%) and night (89%) (Figure 6).

The majority of our lake trout habitat observations indicate they use benthic areas for day and night equally (68%). Lake trout located in benthic areas were found at similar mean depths during day (34 m, SD = 37, range = 10-178 m) and night (31 m, SD = 6, range = 26-42 m). They also utilized similar mean temperatures during day (5.9°C, SD = 2.2, range = 4.3-12.5°C) and night (4.5°C, SD = 0.2, range 4.2-5.0°C). Benthic lake trout were located in similar distances from shore during night (mean = 204 m, SD = 120, range = 15-741 m) and day (mean = 182 m, SD = 148, range 30-556 m).

Lake trout were found in nearshore areas during day (20%) and night (21%). Nearshore lake trout were found in similar mean depths during night (19 m, SD = 8, range 7-26 m) and day (18 m, SD = 9, range = 4-37 m). Mean temperatures for day (7.8°C, SD = 2.1, range 4.3-10.5°C) and night (8.9°C, SD 4.9, range = 4.4-14.5°C) were also comparable. Nearshore lake trout were in similar distances from the shore at night (mean = 202 m, SD = 123, range 90-370 m) and during the day (mean = 115 m, SD = 120, range 30-370 m).

During spring, 12% of our day and 10% of our lake trout night habitat observations were in pelagic areas. Pelagic lake trout utilized a deeper mean depth during the night (38 m, SD = 1, range = 37-38) than day (28 m, SD = 11, range = 13-39 m). Because overall mean depth was shallower during the day, mean temperatures were slightly higher for day observations (6.1°C, SD = 2.2, range = 4.3-5.2°C) compared to night observations (4.5°C, SD = 0.4, range = 4.2-5.2°C). Pelagic lake trout were found in similar distances offshore during the day (mean = 644 m, SD = 625, range = 100-1,389 m) and during the night (mean = 692 m, SD = 249, range = 370-926 m).

Summer—During the summer season we made 117 habitat observations of lake trout, more than half of which (59%) were made during daylight hours. Lake trout utilized all three of our predefined habitat types (i.e., pelagic, nearshore, and benthic), but based on our observations, lake trout were predominantly found in benthic areas during the day (85%). At night, lake trout tended to move into nearshore and pelagic areas and were found in benthic areas 48% of the time. Lake trout utilized pelagic areas more at night (23%) than during the day (9%) (Figure 7).

Though lake trout were found in benthic areas more during the day, mean depth use was similar between day (26 m, SD = 7, range = 17-55 m) and night (28 m, SD = 5, range = 21-41 m). Benthic lake trout were found in similar water temperatures during the day (8.2°C, SD = 2.1, range = 5.2-14.33°C) and night (7.3°C, SD = 0.7, range = 5.9-8.0°C). During the day benthic lake were found in similar distances from shore (mean = 103 m, SD = 299, range = 10-2315 m) as during the night (mean = 82 m, SD = 54, range = 20-185 m).

Lake trout were observed in nearshore areas 6% of the time during the day and 29% of the time during the night. Nearshore lake trout utilized slightly deeper mean depths during the day (29 m, SD = 5, range 22-35 m) compared to night (27 m, SD = 8, range = 13-42 m). Mean

temperature use was similar between day (7.6°C, SD = 1.1, range = 6.6-9.2°C) and night (7.9°C, SD = 2.3, range = 5.0-14.5°C). Nearshore lake trout averaged further from shore during the day (mean = 175 m, SD = 144, range = 50-300 m) than during the night (mean = 53 m, SD = 26, range = 20-100 m).

Pelagic lake trout were found at a shallower mean depth during the day (20 m, SD = 5, range = 16-31 m) compared to night (25 m, SD = 3, range = 20-30 m). Mean temperature use was similar between day (9.0°C, SD = 1.7, range = 6.5-11.8°C) and night (8.6°C, SD = 0.8, range = 7.0-10.0°C). Pelagic lake trout averaged further from shore during the day (mean = 972 m, SD = 721, range = 370-2037 m) compared to night (mean = 766 m, SD = 623, range = 200-2,222 m).

Fall and Winter—During the fall and winter period we monitored the movements and habitat use of nine lake trout and made a total of 63 habitat observations. Lake trout were mostly found in benthic areas (75%), followed by pelagic areas (19%) and nearshore areas (6%) (Figure 6). All of our fall and winter habitat observations were made during daylight hours.

Pelagic lake trout occupied deep water (mean = 44 m, SD = 22, range = 1-77 m) while benthic lake trout used a mean depth of 31 m (SD = 8, range = 16-51 m). Nearshore lake trout occupied shallower mean depths (mean = 21 m, SD = 16, range = 3-42 m). Mean water temperatures were similar for all three habitats and ranged from 6.1°C to 6.7°C. Benthic lake trout averaged closer to shore (mean = 161 m, SD = 141, range = 25-500 m) than nearshore lake trout (mean = 271 m, SD = 212, range = 50-556 m). Pelagic lake trout were found from 150 m to 2,778 m offshore at a mean distance of 1,414 m (SD = 948).
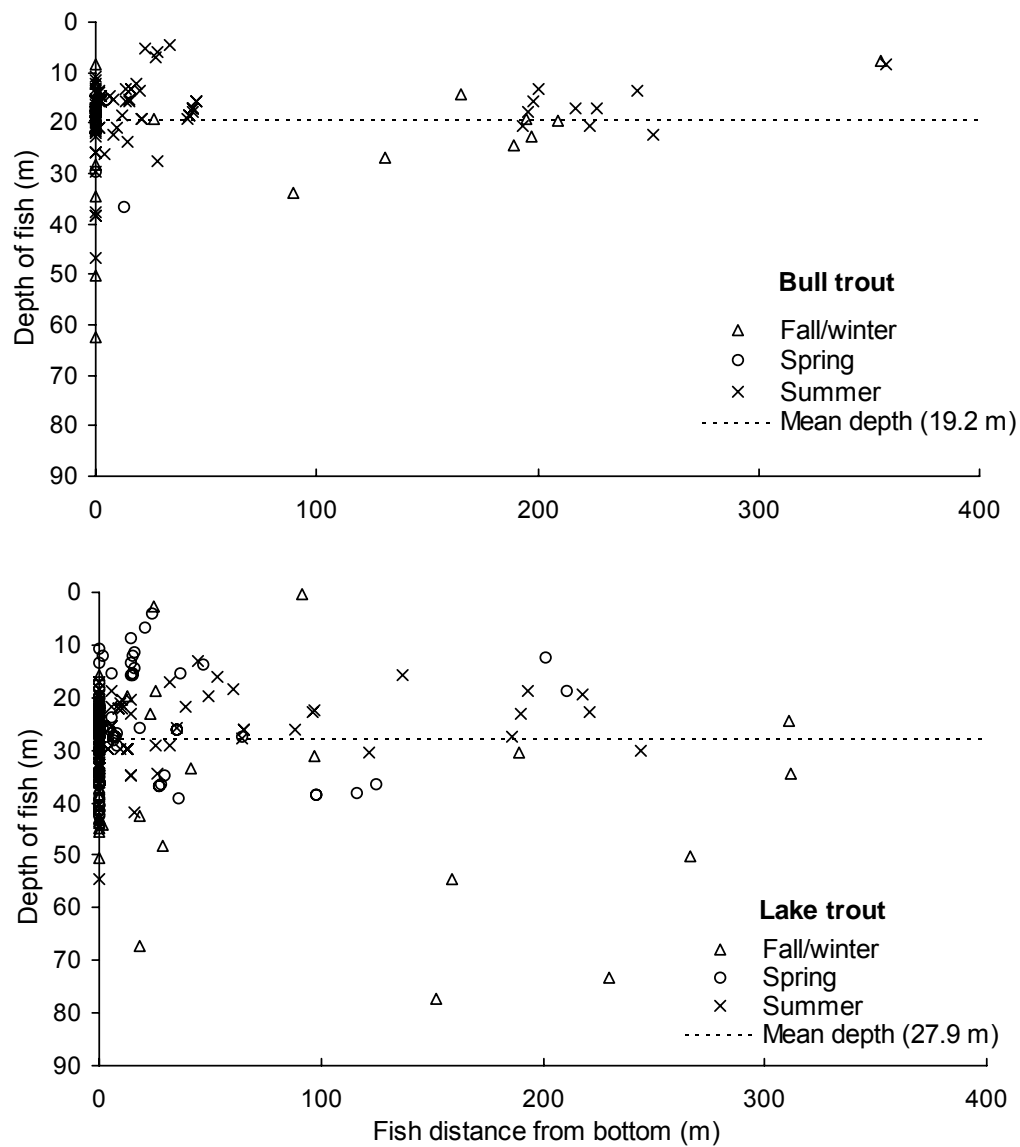
Figure 6.   Seasonal habitat use of lake trout and bull trout in Lake Pend Oreille, Idaho. Graphs depict both day and night observations combined for each season. Marks on the y-axis represent fish found on the lake bottom.
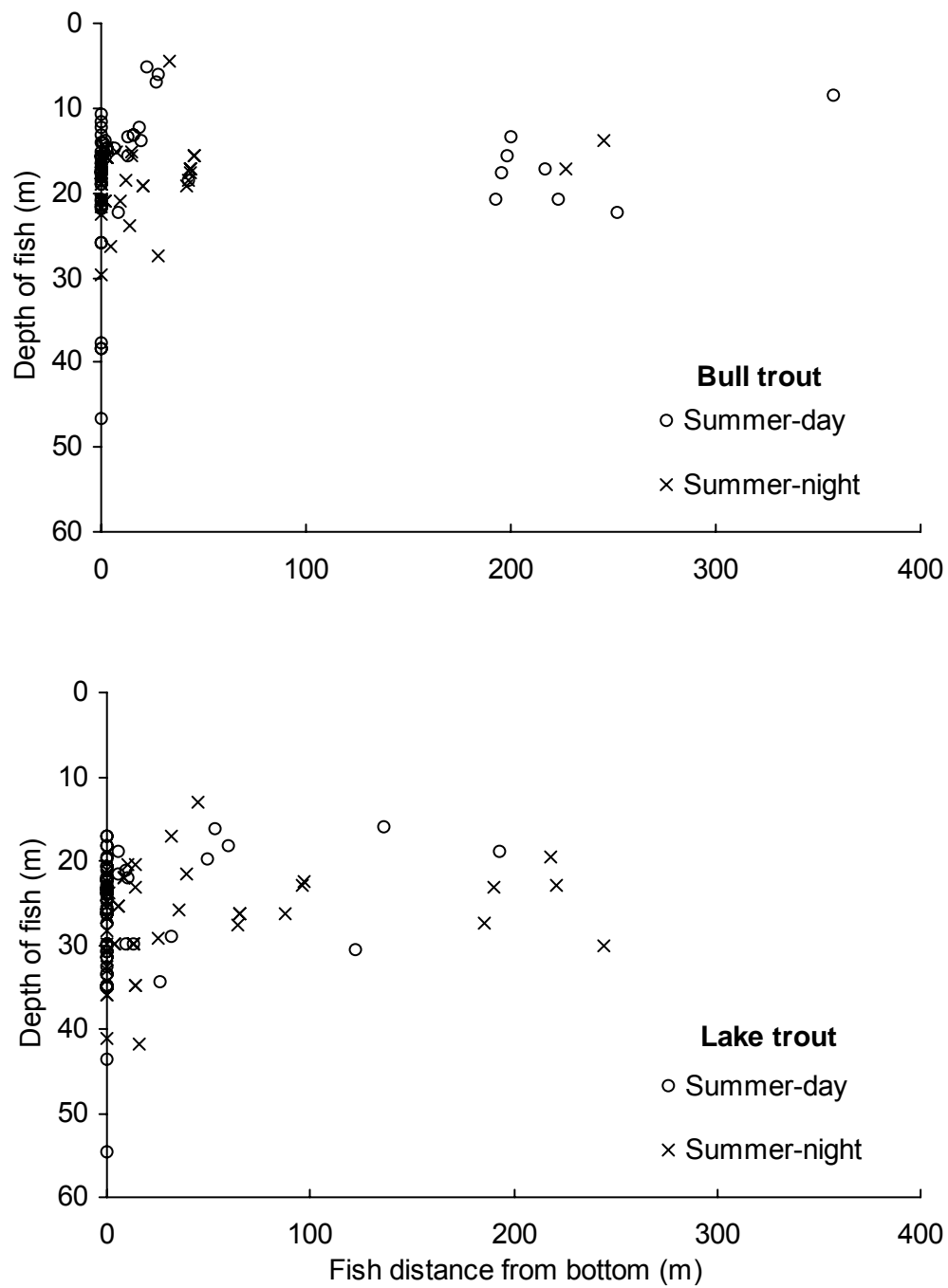
Figure 7.   Day and night summer habitat use of bull trout and lake trout in Lake Pend Oreille, Idaho. Marks on the y-axis represent fish found on the lake bottom.

Rainbow Trout Habitat Use

Spring—Prior to our spring tracking period we had three tagged rainbow trout in the lake. During the spring period, we were only able to locate two of these fish. On May 23, 2003, one of the two remaining rainbow trout was creeled by an angler. The last remaining rainbow trout was tracked to the end of the spring season. In total we made 16 daytime habitat observations during the spring, mostly on one fish (one observation was made on the fish that was creeled).

More than half (56%) of the rainbow trout habitat observations were from the pelagic area. The remaining habitat observations were from fish in nearshore areas (44%). All fish were found in the top 10 m of the water column and nearshore fish were in similar depth (mean = 4 m, SD = 2, range = 2-7 m) as pelagic fish (mean = 3 m, SD = 2, range = 1-5 m). Mean temperature use for all habitat observations was 13.0°C (SD = 1.1, range = 4.9-16.7°C). Mean distance from shore was much greater for pelagic fish (1883 m, SD = 1394, range = 375-4630 m) than it was for nearshore fish (268 m, SD = 138, range = 25-370 m).

Northern Pikeminnow Habitat Use

Summer—During the summer we made 22 habitat observations of one northern pikeminnow. More than half (59%) of these observations were from daylight hours. This northern pikeminnow was exclusively found close to shore (<100 m) and within 10 m of the bottom. Mean depth and temperature use for both day and night was 4 m (SD = 3, range = 1-10 m) and 22.1°C (SD = 2.0, range = 16.8-24.5°C), respectively.

Hydroacoustic Community Identification

Based on 36 nighttime midwater trawls (12 per lake section) in Lake Pend Oreille, kokanee made up the majority of the pelagic fish community found in water depths between 10 and 40 m during August 2003. Kokanee (all age groups) comprised 99% of the composition in sections 1, 2, and 3. Lake whitefish made up the remaining 1% of the pelagic community. Out of 544 fish collected in our trawl gear, all were < 240 mm.

We performed two 2-h and two 4-h gillnet sets on September 19, 2003 and two 10-h sets on September 30, 2003. The nets fished a total of 32 hours and captured two lake whitefish. One lake whitefish (404 mm) was captured in a 4 h set, and the other fish (396 mm TL) was captured in a 10 h set.

Summer hydroacoustic targets utilized for our Shallow Method population estimate were graphed with bull trout and lake trout depth information (Figure 8). Hydroacoustic targets were located between 12 and 30 meters. Two bull trout and nine lake trout observations (4% and 23% of all nighttime habitat observations, respectively) were located within the hydroacoustic layer. Bull trout and lake trout were both predominantly found in benthic and nearshore areas.

24
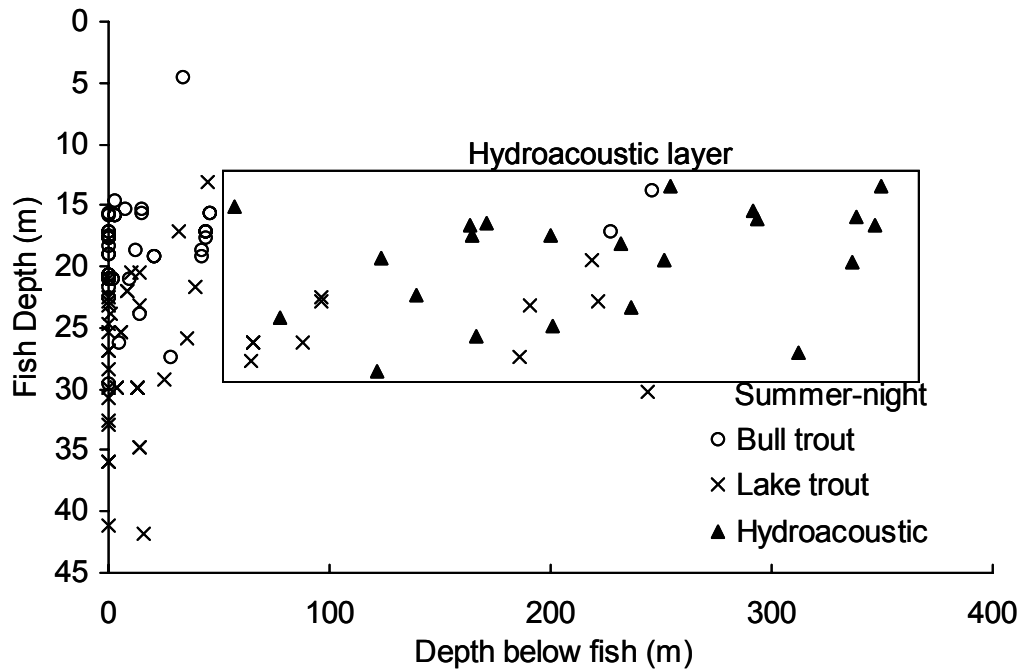
Figure 8.   Nighttime summer hydroacoustic targets combined with locations of tracked bull trout and lake trout.

Predator and Prey Ratio

During August 2003, we estimated there were 30.5 tonnes of large pelagic fish and Maiolie et al. (2004) estimated there were 258.1 tonnes of kokanee (all ages) in Lake Pend Oreille (Figure 9). This accounted for a pelagic predator to prey biomass ratio of 1:8.6 (kg). We derived our large pelagic fish biomass estimate using rainbow trout length and weight data (Irving 1986), thus some error may result for species other than rainbow trout.

Figure 9. Hydroacoustic derived kokanee (all age classes) and large pelagic fish (>415 mm TL) biomass (tonnes) estimates during August 2003 in Lake Pend Oreille, Idaho.

DISCUSSION

Utilizing echo counting for determining large pelagic fish densities in Lake Pend Oreille may be a better method than using echo integration due to a low detection rate of targets. In 2002, we processed our large pelagic fish density estimate using Simrad's EP500 Post Processing software (Version 5.2) (see Bassista and Maiolie 2004 for complete details). This software utilized a tec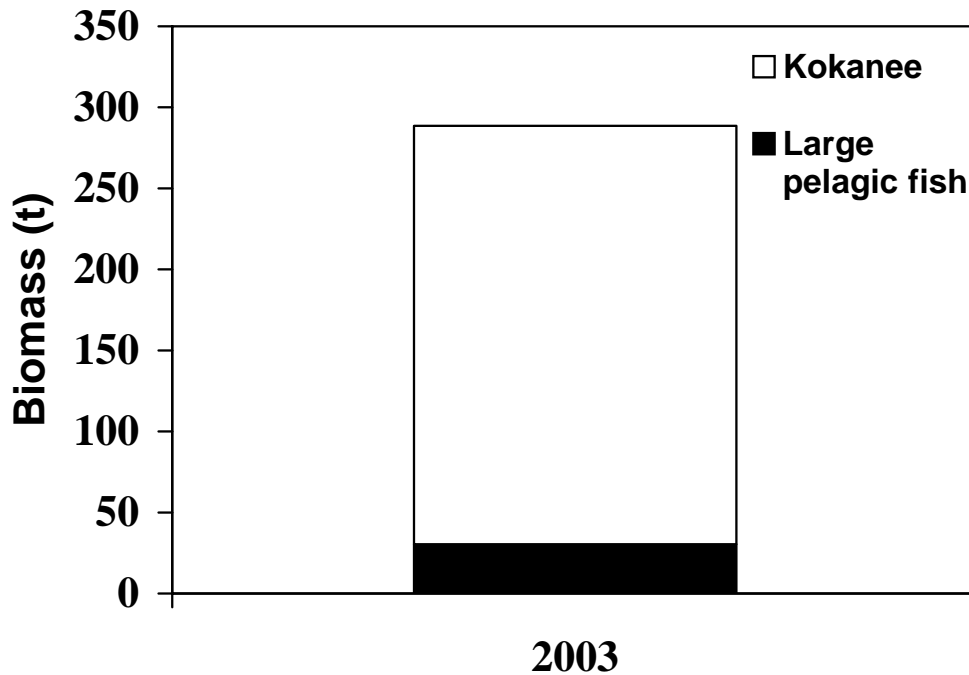hnique called Pelagic Layer Integration (commonly called echo integration) that combined target strength data with volume back-scattering strength (Sv) and provided density estimates for each decibel group (size group) of targets for each transect. This method sums the total reflected energy, or sound intensity, of all fish targets and is most useful when fish densities are too great for echo counting (Brandt 1996). During our 2003 survey, we upgraded our hydroacoustic equipment to Simrad's new EK60 echo sounder and could not process our data using the EP500 software. For our 2003 data set, we estimated large pelagic fish densities by echo counting using Echoview software. It is our opinion that this technique (echo counting) provided a more accurate estimate of large pelagic fish densities, since these targets were rarely encountered and smaller fish did not influence the density estimates. The total pelagic fish estimate (all fish >-33 dB from the entire pelagic area) we calculated in 2002 was more than double the estimate in 2003, and we conclude that our 2002 methods may have overestimated the population due to the backscattering effect of all the targets being included in the echo integration density estimate. Because we used two different methods to determine fish densities, we do not recommend making population comparisons of large pelagic fish between 2002 and 2003.

The sonic telemetry data acquired during this research were used for the purpose of knowing the depth and habitat use of known species. The data were then used to help identify unknown fish found on hydroacoustic echograms. We have assumed that individual observations of tagged fish are independent and they accurately describe depth and habitat use for each species as a whole. We were aware that increased observations, particularly on one fish, might not equate to more data points but only a more precise measurement of that particular fish (Aebischer et al. 1993; Winter 1996; Horton et al. 2004). As we collect telemetry data on more individual fish (during next year's sampling), we will incorporate these data into our analysis.

During our August 2003 nighttime hydroacoustic survey, we found a group of large fish in relatively shallow (mean = 19.3 m) open water, with estimated weights ranging from 1-16 kg. These fish were generally near the top of the nighttime kokanee layer in water of about 11°C and were not in aggregations of similar sized fish. They were fairly well separated from other groups of fish that were clustered at deeper depths or were solitary and near the lake bottom. We hypothesize that these shallow pelagic fish may be mostly comprised of rainbow trout as opposed to lake trout or bull trout. Sonic tracking of nine lake trout and five bull trout during the summer of 2003 suggested that these two species were predominantly found in benthic-nearshore areas; most noteworthy bull trout in which <5% of our nighttime observations were from the pelagic area. We found that lake trout occupied the nighttime pelagic area 23% of the time, so there is a probability that a portion of our large pelagic fish estimate contains lake trout, although the mean depth used by pelagic lake trout was 25.0 m. Under the assumption that most of the large pelagic fish population estimate was comprised of rainbow trout, we estimated the lake contained about 12,000 rainbow trout with a total weight of 31 tonnes. A major effort will be made in 2004 to track rainbow trout and determine their habitat characteristics, particularly at night during the peak of summer stratification, to test this hypothesis. Vidergar (2000) estimated 14,600 rainbow trout in Lake Pend Oreille in 1998 with a 95% CI of –31% to +81%. This estimate was based on a mark-and-recapture study over a two-year period and utilized a large group of cooperative sport anglers. Our acoustic population estimate required one week of field sampling and approximately an additional week of data processing and gave a 90% confidence interval from -39% to +45%. Hopefully, should this method prove successful, rainbow trout estimates can be made on an annual basis so that predator and prey dynamics can be closely monitored.

Two of our project objectives were to determine if pelagic predator and kokanee prey were balanced and to define the point of balance for this assemblage. In 2004, a lake trout population estimate was made by catching approximately 1,000 lake trout in trap nets and marking and recapturing them (Peterson and Maiolie 2004). This study yielded a whole-lake population estimate of 6,376 lake trout >52 cm weighing 23 tonnes. Combining lake trout and large pelagic fish biomass (potentially rainbow trout) yielded a predator:prey ratio of 1 kg of predator for each 4.6 kg of kokanee. Two considerations are that kokanee made up about 80% of the diet of predators (Vidergar 2000) (not their complete diet), and that bull trout, northern pikeminnow, and lake trout <52 cm have not been included in this ratio. Close monitoring of the kokanee population indicated that they increased in biomass during 2003 by 65 tonnes (Maiolie et al. in press). This seemed to indicate that the kokanee prey base in August 2003 was capable of sustaining this potential abundance of predators and still increase in biomass. This was a fairly recent improvement in the kokanee population. Between 1998 and 2001, kokanee progressively declined. This may be an indication that the present 1:4.6 ratio was near the maximum that the prey base could support, and predator management efforts in Lake Pend Oreille should continue to focus on reduction.

We found that downlooking mobile hydroacoustic surveys performed at night estimated a significantly higher abundance of large pelagic fish than during the day. Additionally, night surveys provided a more accurate population estimate than daytime surveys, based on 90% confidence intervals. Our results contradict Teuscher (2001) who concluded that hydroacoustic surveys for rainbow trout were best performed during daylight hours. However, his surveys did not allow for a direct comparison to our work in Lake Pend Oreille, because they were performed in relatively shallow lakes and reservoirs using a fast multiplexing hydroacoustic system capable of both downlooking and sidelooking. Though bull trout and lake trout were not found in pelagic areas often, their difference in depth use between day and night was minimal. This may suggest that depth utilization of predators is not a factor for the difference in day and night surveys. We suspect that the visual presence of our research vessel during daylight hours due to increased light intensity may be causing fish to scatter (MacLennan and Simmonds 1992), while surveys performed at night provide a more "discreet" setting to enumerate large pelagic fish. Luecke and Wurtsbaugh (1993) found that densities of single fish targets (Bonneville ciscoes *Prosopium gemmifer*) were lower during daylight hours compared to nighttime in Bear Lake, Utah and Idaho but concluded this was due to increased schooling of fish targets. Adult rainbow trout, bull trout, and lake trout are not suspected to be schooling species in Lake Pend Oreille, and we conclude that vessel avoidance may have been the limiting factor for lower density estimates of large pelagic fish. We recommend that future hydroacoustic work (using downlooking techniques) with predators in Lake Pend Oreille focus on night surveys.

Based on our hydroacoustic survey and sonic tracking results during spring 2003, we found that spring was most likely an ineffective time to estimate pelagic predator abundance. During our spring hydroacoustic survey (May 28 and 29) we did not detect any pelagic fish >415 mm above 20 m. We did detect 14 fish (>½ of the number of targets used in our population estimate) located between 20 and 60 m. During this time, we relied on sonic tracking data to help us determine if a spring hydroacoustic survey was feasible. We collected numerous data points from lake trout during spring (nine fish with 97 observations) and observed they were in pelagic areas <15% of the time and utilized water depths between 12 and 40 m. Though we had very few habitat observations of rainbow trout (two fish with 16 observations) and bull trout (three fish with five observations), all of the rainbow trout were located above 10 m while bull trout were distributed between 15 and 36 m in nearshore benthic areas. The possibility that our tracking observations were not a representative sample of the entire population is likely, but knowing predators used depths <20 m some or all of the time lessens the likelihood that an accurate estimate would have been obtained during spring, when all areas of Lake Pend Oreille were thermally tolerable for rainbow trout, lake trout, and bull trout (Scott and Crossman 1973; Selong et al. 2001).

Another project objective was to research methods for removal of rainbow trout and lake trout that would not impact bull trout. During the summer of 2003, an increase in kokanee biomass and survival rates was observed (Maiolie et al. 2004). However, weak year classes of kokanee, specifically age-0 and age-1 in 2003, were measured (Maiolie et al. 2004), and kokanee biomass and survival rates may decrease in future years. As kokanee spawning habitat is improved through lake level manipulation (Maiolie et al 2002), it may be vital to reduce predator biomass in Lake Pend Oreille to ensure older age classes of kokanee survive to harvestable numbers. Pelagic gillnetting was shown to be ineffective at capturing large numbers of pelagic fish. If rainbow trout removal is warranted, we recommend efforts focused in spawning tributaries and staging areas (e.g., Pack River and Clark Fork deltas). Surface gillnets in staging areas during the night may prove to be successful, since we found rainbow trout near

the surface in February and March (prespawn periods). Potential removal of lake trout using large trap nets was evaluated in Peterson and Maiolie (2004), and they concluded that trap nets alone in a short time period would probably not suppress the population.

We monitored the depth use and movements of eight bull trout and nine lake trout from September through March in conjunction with the concurrent trap-netting project that occurred from October through March (Peterson and Maiolie 2004). Bull trout and lake trout utilized a mean depth of 27 m and 31 m, respectively. Trap nets were fished between 21 and 52 m and captured a substantially larger number of lake trout (1,100) than bull trout (136). Since depth utilization was similar between bull trout and lake trout, the trap netting data may indicate that Lake Pend Oreille contains more lake trout than bull trout if both species are equally vulnerable to trap netting. Trap net catch rates for lake trout were highest from October to mid November, most likely due to lake trout spawning (Peterson and Maiolie 2004). Adult bull trout migration out of Trestle Creek (a significant spawning tributary for bull trout) drastically decreased by the beginning of October (Downs and Jakubowski 2003), so it is unlikely that a significant portion of the bull trout population was in tributary streams when trap netting commenced. Two of the bull trout that were tracked from November to December showed extensive movements and were located near the trap nets but were never captured by the nets. Lake trout also moved extensively throughout the lake, and one fish was captured in the Thompson Point trap net (Peterson and Maiolie 2004). However, the other eight fish were often found near trap net locations but avoided capture. Our lake trout and bull trout movement information may suggest that trap netting gear was not as effective as it could have been, and modifications to the precise location of the trap nets need to be taken into consideration. Bottom mapping with hydroacoustic equipment before and after net placement may aid in more effective sets.

CONCLUSIONS

This is the second year of a multi-year study, and these conclusions only include the findings from March 2003—February 2004. We found that by separating large pelagic fish >415 mm TL on the basis of depth, location, and determining whether or not the target was in a school, we could obtain a more accurate estimate of a pelagic predator population, especially when using echo counting techniques. We concluded that night surveys for large pelagic fish are far superior to day surveys when using downlooking mobile hydroacoustic techniques in Lake Pend Oreille. We also concluded that spring is an ineffective time to acquire a pelagic predator estimate using hydroacoustics. In August 2003, we estimated that Lake Pend Oreille contained about 12,000 pelagic fish too large to be kokanee. Based on telemetry information, we found that a majority of these large fish are probably not bull trout or lake trout. Data from Maiolie et al. (2004) showed that kokanee survival from age-1 to age-2 was estimated to be 55% from August 2002 to August 2003, which might suggest that predator and prey levels were nearing a balance.

RECOMMENDATIONS

1.   Continue to sonic track fish >415 mm to determine the species composition of the larger targets seen on the hydroacoustic echograms with emphasis on rainbow trout during the summer of 2004.

2. Continue to utilize neutrally buoyant gill nets suspended in pelagic areas to determine species composition of pelagic fish (>415 mm) communities and discontinue midwater trawling.

3. Discontinue spring hydroacoustic surveys, since they will likely miss most of the rainbow trout population and discontinue daytime surveys for large pelagic fish.

4. Continue to estimate kokanee biomass along with pelagic predator biomass. By calculating kokanee survival rates along with predator:prey ratios, we may be able to determine what ratio represents a balanced population.

5. Continue harvest regulations and provide derby incentives aimed at reducing rainbow trout numbers and manage for improved survival rates of kokanee until hydroacoustic methods can be developed to estimate rainbow trout.

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APPENDICES

Appendix A.   Post-processor settings used in Echoview analysis of hydroacoustic data from 2003.

Variable	Setting
Absorption coefficient:	0.00415 dB/m
Sound speed in water:	1455 m/s
Transmit power:	500 w
Two-way beam angle:	-21.00
Volumetric backscattering (Sv) gain:	26.76
Areal backscattering (Sa) correction:	-0.66
Target strength (TS) gain:	26.76
Pulse width:	0.256 m
Frequency:	120 khz
Minor axis angle offset:	0.10°
Major axis angle offset:	0.02°
Minor axis 3dB beam width:	6.81°
Major axis 3dB beam width:	6.76°
TS threshold:	-60 dB
Pulse length determination:	6.00
Minimum normalized pulse length:	0.3
Maximum normalized pulse length:	1.8
Maximum beam compensation:	6.0 dB
Maximum SD of minor axis angles:	0.6
Minimum SD of minor axis angles:	0.6
Minimum Sv:	-33 dB
Maximum TS compensation:	6 dB

Appendix B.   Values used to calculate a 90% confidence interval for our nighttime pelagic fish >415 mm (TL) population estimate in Lake Pend Oreille during August 2003.

Confidence Interval for Predators
>-33 dB Single Trace During Nighttime Acoustic Survey

Sec 1

$\bar{x}$ = 0.28461

s = 0.28126

N_1 = 5605.6

N_1^2 = 31,422,199

FPC = 0.997859

n = 12

Section area (m^2) = 58,834,000

$\bar{x}$ layer depth of fish = 19.1 m

width of beam = 2.2645 m

$\bar{x}$ Length of transects = 4,634.9

Avg transect area = 10,495.6

$N_1^2(FPC)\dfrac{s^2}{n} = 206,705.1$

Sec 2

$\bar{x}$ = 0.07470

s = 0.13903

N_2 = 4,782.8

N_2^2 = 22,875,478

FPC = 0.997909

n = 10

Section area (m^2) = 77,983,000

$\bar{x}$ layer depth of fish = 23.35 m

width of beam = 2.7684 m

$\bar{x}$ Length of transects = 5889.7

Avg transect area = 16,314.5

$N_2^2(FPC)\dfrac{s^2}{n} = 44,123.5$

Sec 3

$\bar{x}$ = 0.21556

s = 0.16182

N_3 = 3,754.2

N_3^2 = 14,094,018

FPC = 0.998402

n = 6

Section area (m^2) = 75,033,000

$\bar{x}$ layer depth of fish = 21.05 m

width of beam = 2.4957 m

$\bar{x}$ Length of transects = 8,008.3

Avg transect area = 19,986.3

$N_3^2(FPC)\dfrac{s^2}{n} = 61,412.0$

n = number of samples in that section
N = Total number of times possible in that section

t_{27}^{90} = 1.703

$\sum N^2(FPC)\dfrac{s^2}{n} = 312240.6$

$\bar{x} \pm t^{90} * \sqrt{\dfrac{1}{N^2}\sum N^2(FPC)} =$

90% C.I. = 0.191405 $\pm$ 0.06729 (0.12411 to 0.25869)
90% C.I. for fish density = 0.5538 fish/ha (0.3308 fish/ha to 0.8142 fish/ha)

Sec 1 = 5,447 fish
Sec 2 = 1,464 fish
Sec 3 = 4,822 fish
Total = 11,733 (-40%, +47%) or (7,007 to 17,251)

Prepared by:

Approved by:

IDAHO DEPARTMENT OF FISH AND GAME

Thomas P. Bassista
Fisheries Research Biologist

Virgil K. Moore, Chief
Bureau of Fisheries

Melo A. Maiolie
Principal Fisheries Research Biologist

Daniel J. Schill
Fisheries Research Manager

Mark A. Duclos
Fishery Technician